Solar Spectral Radiometer

Denise Hagan
Jet Propulsion Laboratory
California Institute of Technology

The Solar Spectral Radiometer (SSR) measured hemispheric broadband and spectral downwelling solar irradiance during CRYSTAL FACE. The first flight of the instrument took place from Ellington Field in late June 2002 aboard the NASA WB57. A week later the instrument ferried to Key West for the Florida Area Cirrus Experiment. The SSR operated in autonomous mode for the duration of the CRYSTAL mission. Data were collected for every WB57 flight.

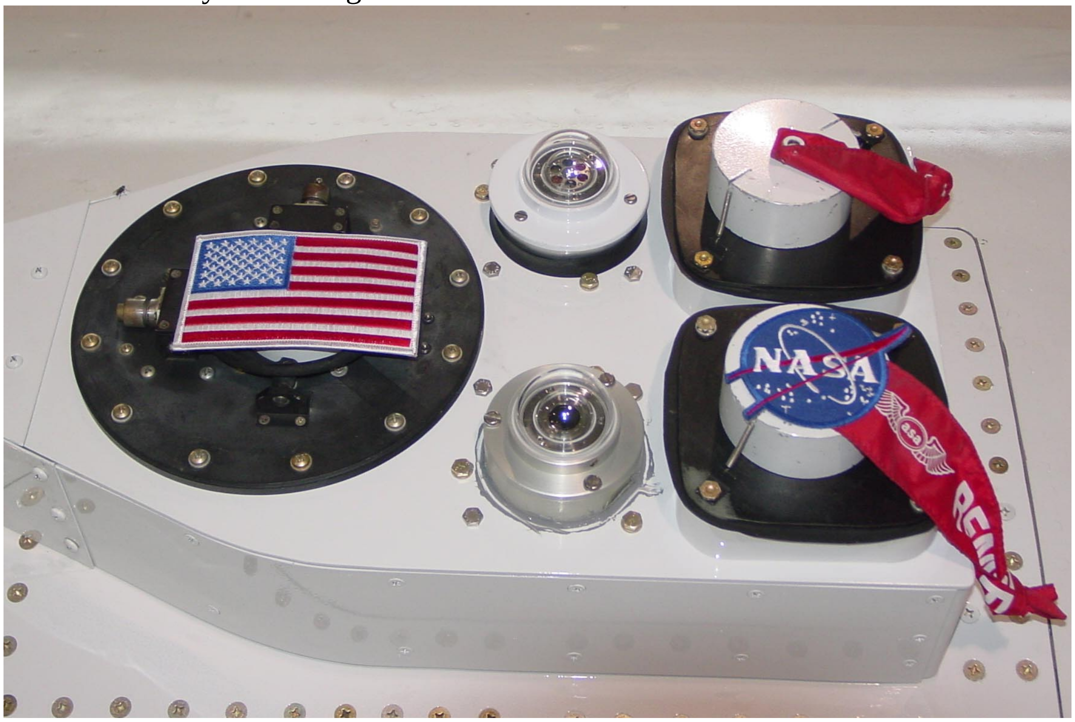

Figure 1. Radiometers on WB57 mounting plate. The JPL SSR and commercial Eppley are centered side by side, with the SSR at the top. Protective plates cover the RAMS instruments.

Although the instrument was deployed primarily as a technology demonstration, the instrument obtained useful measurements for studies of atmospheric solar transmission. This paper briefly describes the instrument and provides examples of measurements obtained during several flights in a variety of cloud conditions. The observations are presented in terms of relative response. Corrections will be applied for effects of instrument orientation relative to the direction of the sun, using software made available by P. Pilewskie (Ames). This geometrical correction accounts primarily for changes in the irradiance with respect to aircraft tilt. Other required corrections are the first order departure of the detector from a true cosine response and temperature compensation of the detector. Corrected observations will be available this spring.

Examples of observations obtained by the broadband channel of the instrument (350–2700 nm) and several bandpasses that subdivide this region are provided in Figures 3 through 5. Figures 3-4 compare the SSR broadband channel with measurements by a commercial Eppley PSP, and with a small subset of observations obtained by the RAMS instrument. Figures 9-12 compare the bandpass observations, normalized to the broadband channel and offset slightly to show relative changes. In situ water measurements obtained by the JPL ALIAS instrument are also provided to indicate presence of cloud along the WB57 flight track.

Instrument Description

The SSR was developed to take advantage of microthermopile detector technology developed at JPL. The main features of these detectors are fast response relative to conventional thermopile detectors and multiple discrete detection capability in an area occupied by a single conventional detector. During CRYSTAL FACE, the SSR was flown side-by-side with an Eppley PSP (Figure 1). The Eppley is absolutely calibrated and traceable to World Standard

Instrumentation and thus provides a calibration transfer for the SSR. The two instruments were mounted next to RAM instruments that have a long measurement history. The SSR and Eppley are shown in Figure 1 in their mounting configuration on the WB57. Protective cover plates hide the RAMS instruments.

The SSR has seven broadband thermopile detectors, each having a 1mm^2 detection area on a 5 mm silicon substrate (Figure 2). The central detector receives unfiltered light. Six detectors spaced at 60˚ intervals surround the central detector. Five of the surrounding detectors have interference coatings covering the spectral bands 350-450 nm, 450-600 nm, 600-820 nm, 820-1200 nm, and 1200-2000 nm. Over the detector/filter assembly are two concentric glass domes. The radiometer body houses a preamplifier assembly as well as thermistors for monitoring of instrument temperature.

The sensitivity and response (1/e) time for the micromachined thermopile detectors is 15 μV/(Wm^{-2}) and 15 ms in air. In comparison, the thermopile detectors used in the industry standard Eppley Precision Spectral Pyranometer, have a 1 cm^2 area, a sensitivity in air of 9 μV/(Wm^{-2}) and a response (1/e) time of 1 s. The microthermopiles are linear to within 1% for incident energies from 2 μW to 3 mW, corresponding to 2 Wm^{-2} to 3000 Wm^{-2}. The total deviation in response over the temperature range -50 to 50 ˚C is 6% in air. For accurate radiometric calibration, the temperature dependence of each channel is measured, as it is in other types of radiometers. The pressure dependence of sensitivity for a micromachined thermopile detector varies less than 1% from 1 atmosphere down to 200 mbar, which is more than adequate for tropospheric measurements.

Filter Transmission

The approximate in-band transmission, and total direct sunlight transmitted for each filtered detector is shown in the following table. The calculation assumes that the sun is an ideal 5900 K blackbody with 1000 W/m^2 incident on the radiometer. Because the filters are flat interference filters, the transmission bands will shift with increasing zenith angle. The geometry of the filters and detectors limits light detected by the filtered detectors to high solar zenith angles (≤50˚).

Spectral Bandpass (nm)	Transmission (%)	Total Direct Sunlight Transmitted in Bandpass (W/m^2)
350-450	55	65
450-600	70	140
600-820	60	130
820-1200	55	110
1200-2000	70	91

Figure 2. SSR photograph showing detectors without optical filters.

Cosine Response

The cosine response of the SSR normalized to the Eppley is shown in this table. The instruments were mounted on a common plate, with a sun tracking apparatus. Data were obtained at five tilt angles from direct incidence for each of four azimuth angles.

Azimuth Angle	Tilt Angle 0˚	10˚	20˚	30˚	40˚	50˚
25˚	0.974	0.978	1.00	0.964	0.980	0.967
115˚	0.989	0.990	1.00	0.966	0.999	0.998
205˚	0.947	0.964	0.985	0.979	0.997	1.000
295˚	0.879	0.907	0.925	0.947	1.000	0.98

SUMMARY

Cloud and aerosol radiative forcing and cirrus cloud parameterizations in radiative transfer models depend on an accurate understanding of absorption and scattering of solar radiation. To obtain a reasonable understanding of these phenomena, simultaneous broadband and spectral measurements of downwelling radiation are needed as a function of altitude. In particular, spectral data in the near infrared contains vital information on absorption by water vapor and scattering by aerosols. To our knowledge, no lightweight, compact radiometer exists that can measure total solar incident energy (200-2700 nm) simultaneously with spectral energy distribution out to 2000 nm using detector technology common to all wavelengths.

The SSR has a unique combination of characteristics that allow it to provide scientific data not easily available with any other technique. These characteristics include:

1. **Fast response**. The devices stabilize to within 1% of final value after 75 ms. The stabilization time is five times the 1/e detector response time. In comparison, the industry standard Eppley pyranometer stabilizes in 5 to 10 s. Fast response allows more accurate measurements from airplanes, particularly in partly cloudy conditions. For example, for a research airplane traveling at 100 m/s, the JPL radiometer will stabilize within a distance of 25 m, while the Eppley radiometer travels at least 500 m before stabilizing. This stabilization time is five times the 1/e detector response time. In comparison, the industry standard Eppley pyranometer stabilizes in 5 to 10 s. Fast response allows more accurate measurements from airplanes, particularly in partly cloudy conditions. For example, research airplanes typically travel at 100 m/s, so the JPL radiometer will stabilize within a distance of 25 m, while the Eppley radiometer travels at least 500 m before stabilizing.

2. **Broadband simultaneous with spectral channels**. The central thermopile detector measures total energy in the range 200-2700 nm, limited by the dome transmission. Standard pyranometers detect either broadband radiation or a single spectral band. Spectral instruments typically use silicon detectors, which are sensitive only up to 1100 nm and cannot accurately measure broadband incident power. The JPL instrument has bandpasses from 350-2000 nm. The simultaneous precise measurement of broadband radiation and spectral radiation distribution can provide an improved understanding of atmospheric absorption processes.

4. **Compact size, and portability**. The SSR weighs less than 1 kg and is about 9 cm in diameter. Power requirements are low.

5. **Reliability**. The SSR performed without failure during the CRYSTAL FACE mission. The instrument worked autonomously, collecting data over multiple flights without technical intervention.

6. **Accuracy**. The SSR instrument responses are traceable to World Standard Instrumentation. The detector linearity and pressure dependence of sensitivity is less than 1%. Temperature measurements needed for temperature compensation of the detectors were acquired with an absolute accuracy of 0.1%. All necessary ancillary aircraft information are available to correct the instrument orientation relative to the direction of the sun and to correct for the first order departure of the detector from a true cosine response (the residual cosine error is less than 0.5%). With the application of appropriate

correction algorithms for known instrument response characteristics, the SSR can measure solar spectral irradiance with very high absolute accuracy.

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For further information, please contact
Dr. Denise Hagan M/S 169-237
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA, 91109
Phone 818: 354-7073
Email denise.e.hagan@jpl.nasa.gov

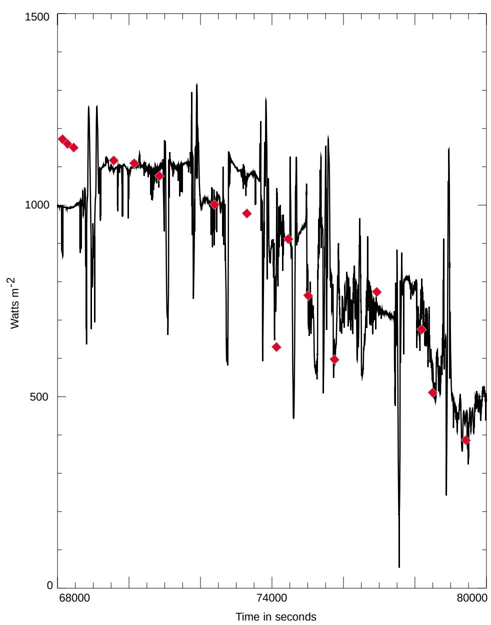


Figure 3. Time series of broadband measurements (W m^{-2}) for July 16. Black =Eppley; red =RAMS subset.

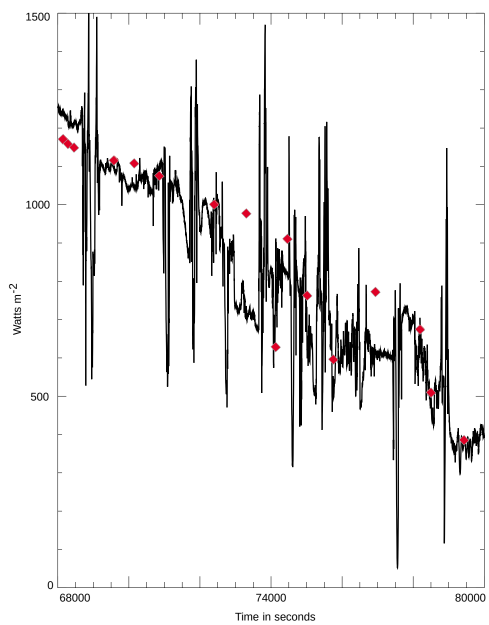
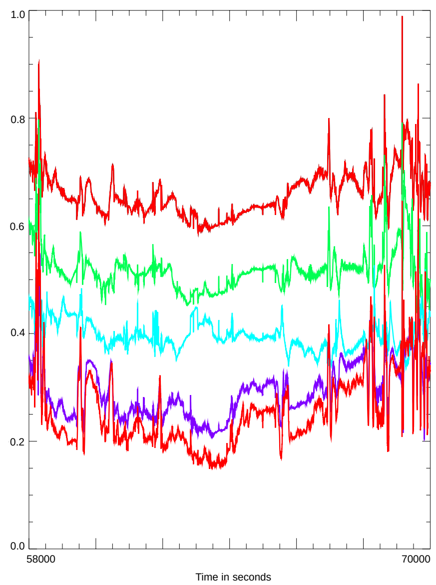


Figure 4. Time series of broadband measurements (W m^{-2}) for July 16. Black =SSR; red= RAMS subset.



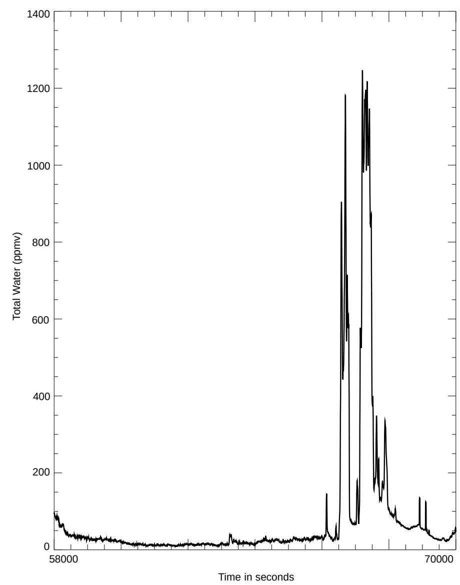
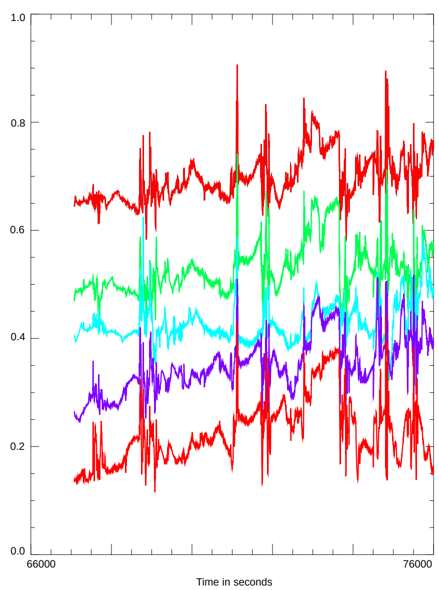


Figure 5. Time series of SSR bandpass measurements for flight on July 11. The five spectral bandpasses are ratioed to the broadband SSR bandpass; small offsets were applied to separate the time series. The near infrared bands have the lowest ratios.

Figure 6. Time series of ALIAS in situ water measurements on July 11. Spikes and elevated values indicate presence of cloud.



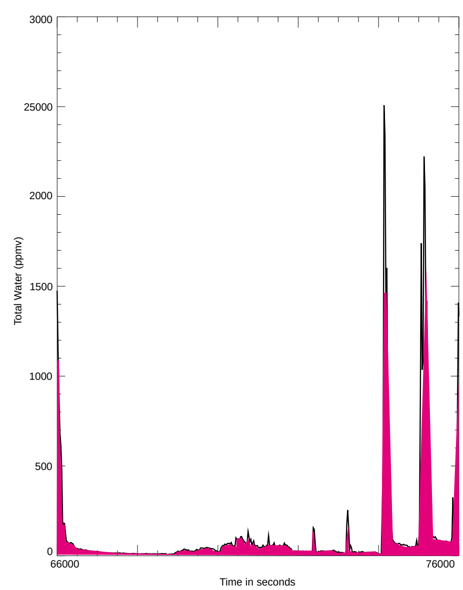
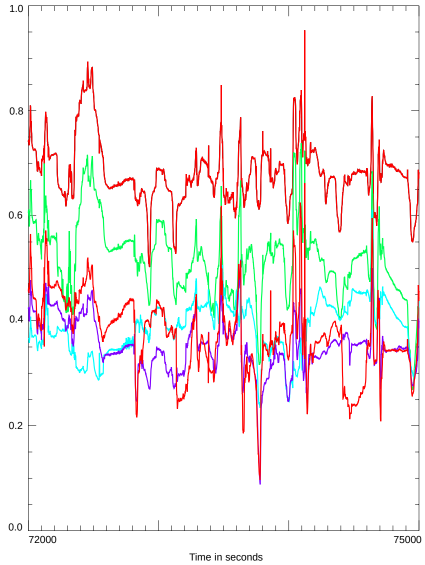


Figure 7. SSR data acquired July 16. (See figure caption 5.)

Figure 8. ALIAS data acquired July 16. (See figure caption 6.)



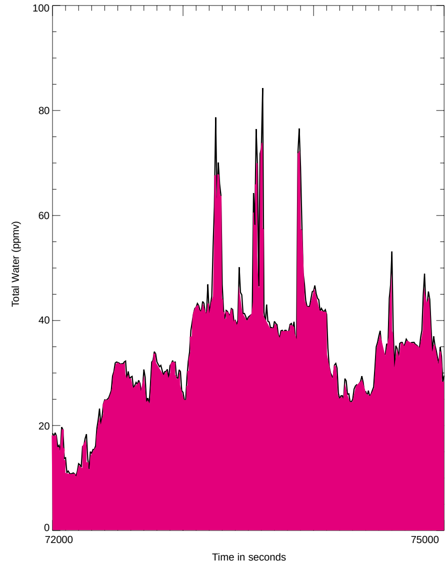
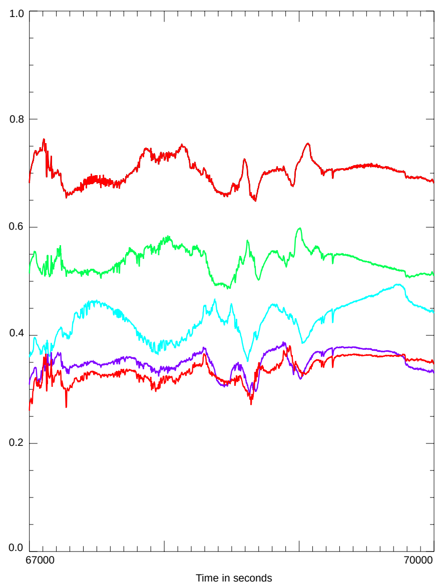


Figure 9. SSR Data acquired July 19. (See figure caption 5.)

Figure 10. ALIAS data acquired July 19. (See figure caption 6.)



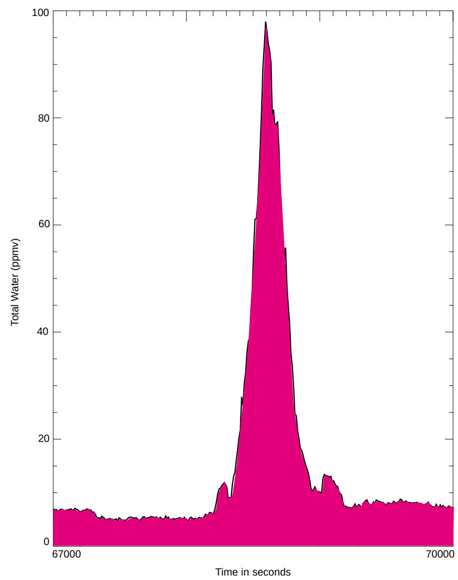


Figure 11. SSR Data acquired July 26. (See figure caption 5.)

Figure 12. ALIAS data acquired July 26. (See figure caption 6.)